Modeling and Forecasting the 2015 Oleg Naydenov Oil Spill near the Canary Islands

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Abstract

In April 14, 2015, the ship 'Oleg Naydenov' sank near the coasts of the Canary Islands with around 1400 tons of oil in its tanks. Currently, this oil is spilled in the sea and presents a real danger of heavy pollution for the Canary Islands. There is an urgent need of tools that allow to forecast the movement of this particular oil spill and asses the way to clean it. The main goal of this work is to apply a model developed previously to simulate the evolution of oil spills to this particular hazard. The concentration of the pollutant is subject to the effects of wind and sea currents and diffusion. This implies that the mathematical model is of the advection-reaction-diffusion type. Here, we briefly recall the considered mathematical model. Then, we solve two particular numerical experiments using this model with data from the Oleg Naydenov hazard. One experiment aims to validate our approach and the other one propose a forecast of this event up to May 9, 2015.

Keywords: *Numerical Simulation; Advection-reaction-diffusion equations; Sea pollution; Oleg Naydenov.*

Preliminary note on the limitations of the model and the forecast

It is important to highlight the following limitations of this work:

- This document present a work in progress and requires a deep revision.
- The model is designed to consider low or moderated wind velocities (lower than 50 km/h). In case of storm, there is no guarantee of validity of the model outputs.
- The model proposed here does not take into consideration possible cleaning methods. Some examples of models including cleaning methods (e.g., focusing on skimmer ships) are given in [2, 5].
- Considering the forecast, no data about the exact amount of oil spilled in the sea was available (only a coarse approximation).
- Few satellite images of the situation of this particular oil spill were publicly available during this work.

Figure 1: NASA satellite image presenting the oil spill situation at April, 21 2015. The zone of interest is inside the red square. The ship position is represented by a blue circle and the current oil spill situation with a black line.

1 Introduction

The ship 'Oleg Naydenov' sank near the Canary Islands coasts in April 12, 2015. The tanks of this ship were filled with around 1400 tons of oil. This oil starts to be spilled into the sea with a flow between 5/10 liters per hours (see [9]). This oil spill presents a real danger of heavy pollution for the Canary Islands, with some oil spots who have yet reached their coasts (see [10]). A NASA satellite image presenting the oil spill situation at April 21, 2015 is shown on Figure 1 (see [11]). Regarding the emergency of this situation, any tool allowing to understand and to forecast the evolution of the oil spill is required.

To this aim, we propose here to use a model developed in previous works [2, 5, 6] to simulate and to forecast the evolution of this particular oil spill [2]. This model, based on a second order finite volume approximation of an advection-diffusion-reaction equation [4], took into consideration: the motion of oil spots resulting from the combined effects of diffusion and of transport by wind and sea currents. It was yet applied to simulated the evolution of the Prestige hazard occurring near Galicia, Spain, in 2002 [1]. In Figure 2, we present a solution obtained with our model of the November 17, 2002 Prestige situation and the satellite image taken by the Envisat ASAR satellite (property of the European Spatial Agency) at the same date. We can observe that graphically both images present similarities regarding the general behavior of the oil spill shape.

Considering those previous results, we want to apply this model to the current Oleg Naydenov hazard. to this aim, we first obtain data from this event in order to calibrate the parameters of our model. Then, we simulate the evolution of the oil spill from April 14, 2015 to May 1, 2015 (first forecast done during this event) and compare with real observations at May 2, 2015. Finally, we perform a last forecast up to May 9, 2015 (last data of wind and sea currents available when the numerical experiments were performed).

In Section 2, we present the mathematical model we use to simulate the motion of the oil spots. In Section 3, we describe the considered numerical experiments based on the 2015 Oleg Naydenov oil spill data and discuss these results. One experiment is used to validate our approach and the other

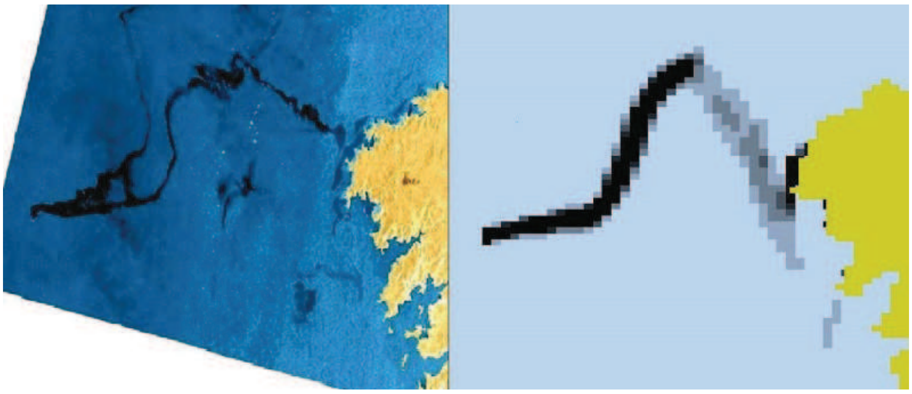

Figure 2: **(Left)** Satellite image of the Prestige oil spill situation taken by the Envisat ASAR satellite (European Spatial Agency) at November 17, 2002. **(Right)** Oil concentration simulated by the model presented in this work for the same date and same event. The coast is also represented in green.

one propose a forecast of this hazard.

2 Mathematical model

We present here the mathematical model used to simulate the evolution of the oil spots concentration, due to the effects of the sea current, wind velocity fields and the pumping process during a time interval $(0, T)$, as previously introduced in [6].

We consider a spatial computational domain $\Omega \subset (x_{1,\min}, x_{1,\max}) \times (x_{2,\min}, x_{2,\max}) \subset \mathbb{R}^2$. The land domains are not included in Ω. We denote by $\partial\Omega_o$ the boundary of Ω in the open sea and by $\partial\Omega_c$ the boundary in the coast. We assume for simplicity that the density of the pollutant is smaller than the one of the sea water (so that it remains at the surface) and the layer-thickness of the pollutant is a known constant h. In practice, the value of h depends on the color of the oil in the water [8].

We denote by $c(x, t)$ the pollutant superficial concentration, measured as the amount of pollutant per surface area at $\{x, t\} \in \Omega \times (0, T)$. We assume that the evolution of c is governed by a source of contaminant which is taken as a circle of radius R_s that follows a trajectory $\zeta \in C^1([0, T], \mathbb{R}^2)$ and spills an amount of oil $S(t)$ per unit of time, by the effect of the diffusion of the pollutant, by the transport due to the wind and sea currents.

In order to avoid the undesired effect of diffusion propagating at infinite speed, we control the velocity of the diffusion propagation using a nonlinear diffusion term. We have also included a boundary condition with appropriate absorbing properties to simulate the behavior of the computed solution near the boundary of the computational domain.

This model is given by

$$\begin{cases} \dfrac{\partial c}{\partial t} - \nabla \cdot \dfrac{c^\kappa}{c_{\text{ref}}^\kappa} \mathbf{d} \nabla c + \nabla \cdot c\, \mathbf{w} + \nabla \cdot c\, \mathbf{s} = \dfrac{S}{2\pi R_S} \chi_{B(\zeta(t), R_s)}, & \text{in } \Omega \times (0, T), \\ L \dfrac{\partial c}{\partial t} + \Big[- (\mathbf{w} + \mathbf{s} + \mathbf{p}_{\text{tol}}) c + \dfrac{c^\kappa}{c_{\text{ref}}^\kappa} \mathbf{d} \nabla c \Big] \cdot \mathbf{n} = 0, & \text{on } \partial\Omega_o \times (0, T), \\ \Big(\dfrac{c^\kappa}{c_{\text{ref}}^\kappa} \mathbf{d} \nabla c \Big) \cdot \mathbf{n} = 0, & \text{on } \partial\Omega_c \times (0, T), \\ c(0) = c_0, \end{cases} \tag{1}$$

where:

- $B(a,b)$ is the ball of center a and radius b.
- $\chi_{B(a,b)}(x) = \begin{cases} 0, & \text{if } x \in \Omega \backslash B(a,b), \\ 1, & \text{if } x \in B(a,b). \end{cases}$
- The function c_0 is the initial superficial concentration; we assume that c_0 has a compact support in Ω.
- $\mathbf{d} = \begin{pmatrix} d_1 & 0 \\ 0 & d_2 \end{pmatrix}$, d_1, d_2 (both >0) being the diffusion coefficients in the west-east and south-north directions.
- $\mathbf{w}$ is the horizontal components of the wind velocity multiplied by a suitable drag factor.
- $\mathbf{s}$ is the see current velocity.
- c_{ref} is a reference pollutant concentration (here, $c_{\text{ref}} = 1$), and $\kappa > 0$ (typical values of κ being 1, 2 and 3).
- $L = \sqrt{(x_{\max} - x_{\min})^2 + (y_{\max} - y_{\min})^2}$ is the characteristic size of the domain Ω.

To limit the artificial diffusion effect typical of this kind of numerical model [4], we use second order accurate time discretization schemes with nonlinear limiters to treat the advection. The full scheme of the considered numerical model can be found in [6].

3 Numerical experiments

In this Section, we present and discuss the considered numerical experiments based on data from the Oleg Naydenov Oil Spill. The first experiment, presented in Section 3.1, aims to validate the oil concentration evolution predicted by the model by comparing the results with the NASA available at April 21, 2015. Then, in Section 3.2, we simulate the possible evolution of the oil spill up to May 9, 2015.

3.1 Validation of the model

We first want to study the validity of the evolution of the oil concentration predicted by our model applied to the Oleg Naydenov hazard.

We consider model (1). Then, we simulate the oil concentration evolution from the beginning of the event from 14 to 21 of April 2015 (date for which a satellite image is available). Considering this time interval, we use the following model parameters:

- $\Omega \subset [-18, -13] \times [24, 29.5]$ (in longitude-latitude coordinate system) which is assumed to be large enough to avoid the oil concentration leaving this domain during the considered time interval. Ω and the considered land are presented on Figure 3. We note that due the the simplified coast database used in this work (provided by Mathworks, in Matlab 2014a) three small islands are missing on the left of this domain. In addition, another computational domain focusing on the main part of the oil spill, denoted by $\Omega_z \subset [-17, -15] \times [26, 29]$, is also considered in order to give a more precise representation of the contamination in the most affected areas.

- The velocity fields $\mathbf{w}$ and $\mathbf{s}$ are estimated by considering historical discrete data provided by the research center Mercator Ocean (Website: `http://www.mercator-ocean.fr`) and by the Website: `http://www.myocean.eu/` and completed by 3D spline interpolation to be able to obtain values at points with no data. The considered drag factor is 1 for the sea currents and 0.022 for the wind [6].

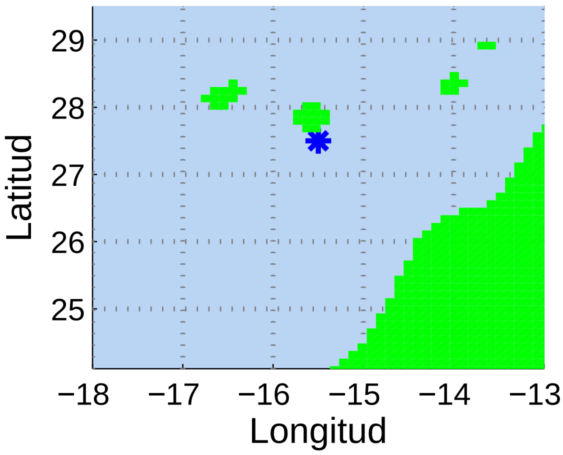

Figure 3: Computational domain Ω considered for the numerical experiments presented in Section 3. The land is presented in green. The position of the Oleg Naydenov ship is represented by a blue star.

- The diffusion coefficient d is set to $0.5(\mathrm{m.s}^{-1})$ [2, 3].
- The position of the ship is [-15.5 27.5] (in longitude-latitude coordinate system). We assume that the tanks of the ship are filled with 1400 tons of oil. The oil spill started at 14 April, 2015 and around 7.5 litters per hour of contaminant are spilled in the sea until reaching 1400 tons. Thus, we set $S(t) = 0.08639(kg.s^{-1}), t \in [0, 1.63e6]$ (s) (by taking $R_s = 1$ (m)).
- $\kappa = 1$ [6].
- For the numerical finite volume scheme used to approximate the solution of model (1), we consider a 100×100 spatial mesh and a maximum time step of 1 hour and half and satisfying the 1-CFL condition. All other parameters are given in [6].

Taking into consideration those values, we present in Figure 4 the solution given by our numerical model on April 21, 2015. In the same figure, we also show the satellite image taken by a NASA satellite at the same date. We can observe that both images present similarities regarding the general behavior of the oil spill shape. This indicates that our model predicts reasonably well the evolution of the oil concentration of the Oleg Naydenov case. However, this figure also exhibits the limitations of our model which neglect to consider some complex effects of the sea currents on the oil.

3.2 Forecasting the Oleg Naydenov oil spill

In this section we propose two forecasts. The first one was done at April, 25 2015 and is compared to real observations obtained at May 2, 2015. The second one was done at May 3, 2015 and simulates the evolution of the oil spill up to May 9, 2015.

3.2.1 Forecast up to May 1, 2015

We present in Figure 5 the solution given by our numerical model at April 27, 2015, April 29, 2015 and May 1, 2015. We can observe that, on April 27, 2015, the oil spill is close to 'Gran Canaria' Island coasts with a risk of high contamination at this date. Then, the main oil spot is moving to the West and reach around May 1, 2015 an area near the south coasts of the 'Tenerife' Island. From this forecast, we see the necessity to clean and contain the oil spill in next days in order to avoid high contamination

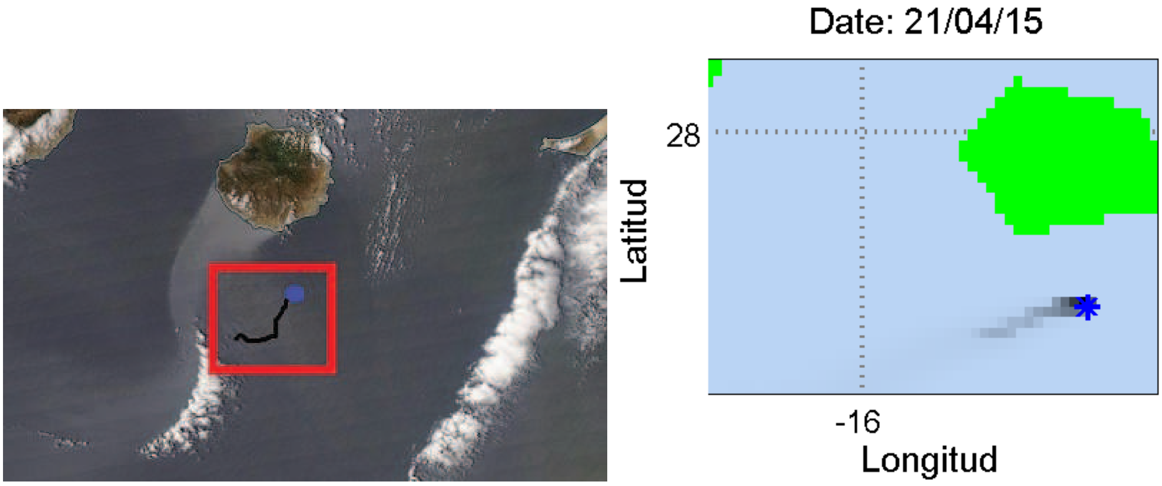

Figure 4: **(Left)** NASA satellite image presenting the oil spill situation at April 21, 2015. The zone of interest is inside the red square. The ship position is represented by a blue circle and the current oil spill situation with a black line. **(Right)** Oil concentration simulated by the model presented in this work for the same date and considering the computational domain Ω_z. The coast is also represented in green. The position of the Oleg Naydenov ship is represented by a blue star.

of both islands (and small western neighbourhood islands not represented in our domain). Eastern Canary Islands seem to be safe from contamination. We observe that minor oil spots (in light grey) reach the south of the computational domain and may produce a contamination in open sea which can affect African coasts in the future.

At April 29, 2015 two oil spots were observed near the western coasts of 'Gran Canaria' and were cleaned by authorities [12]. Furthermore, at May 2, 2015 small oil spots have reached various southern and south-western beaches of 'Gran Canaria', in an area highlighted by the model [13]. However, up to now, no oil spot was observed near the eastern costs of 'Tenerife'. Those observations seem to indicate that our model present a reasonable accuracy in simulating the oil spill evolution.

3.2.2 Forecast up to May 9, 2015

We present in Figure 6 the solution given by our numerical model at May, 5 2015, May, 7 2015 and May, 9 2015 (the last date with available data of wind and sea currents). In that case, we see that the oil spill moves in the south-west direction but, this time, far from the coast of 'Tenerife'.

In addition to this forecast, as the drag factor remains unknown and was assumed the same as the Prestige case [6] in previous experiments, we perform the same forecast up to May 9, 2015 with drag factors of 0.011 and 0. The solution given by our numerical model at May, 9 2015 considering the drag factors 0.022, 0.011 and 0 are presented on Figure 7. We observe that considering the drag factor 0.011 does not change significantly the general behaviour of the solution. However, when no wind is considered, the sea currents between 'Gran Canaria' and 'Tenerife' push the oil spill to the west.

Finally, in Figure 8, we present the sum at each model time step of the oil concentration at each point in the domain Ω considering a drag factor of 0.022. We see that the south-western area is the most affected region. Open sea was highly affected by this hazard.

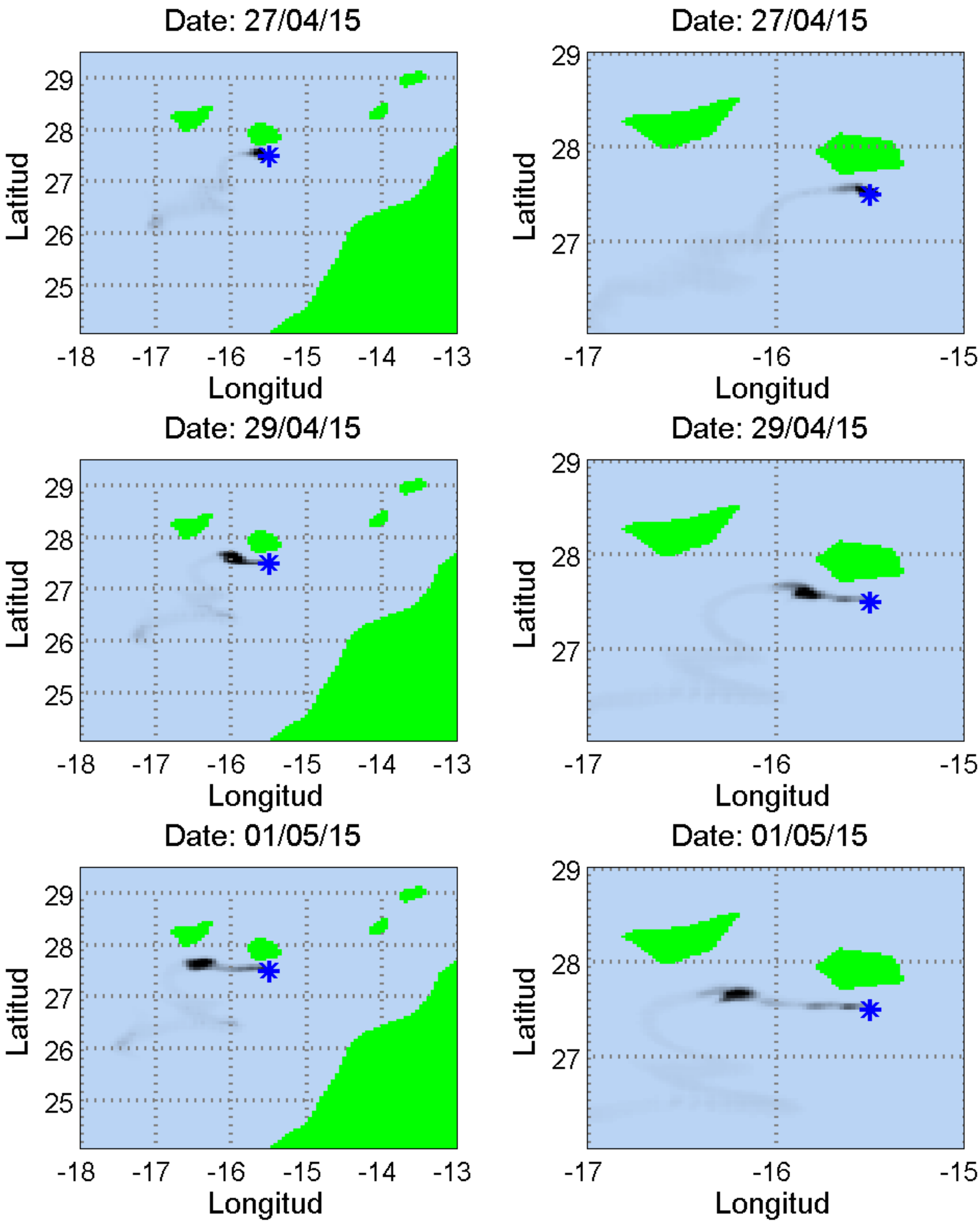

Figure 5: Oil concentration simulated by the model, considering the computational domains **(Left)** Ω and **(Right)** Ω_z,presented in this work for the dates: **(Top)** April 27, 2015, **(Middle)** April 29, 2015 and **(Bottom)** May 1, 2015. The coast is also represented in green. The position of the Oleg Naydenov ship is represented by a blue star.

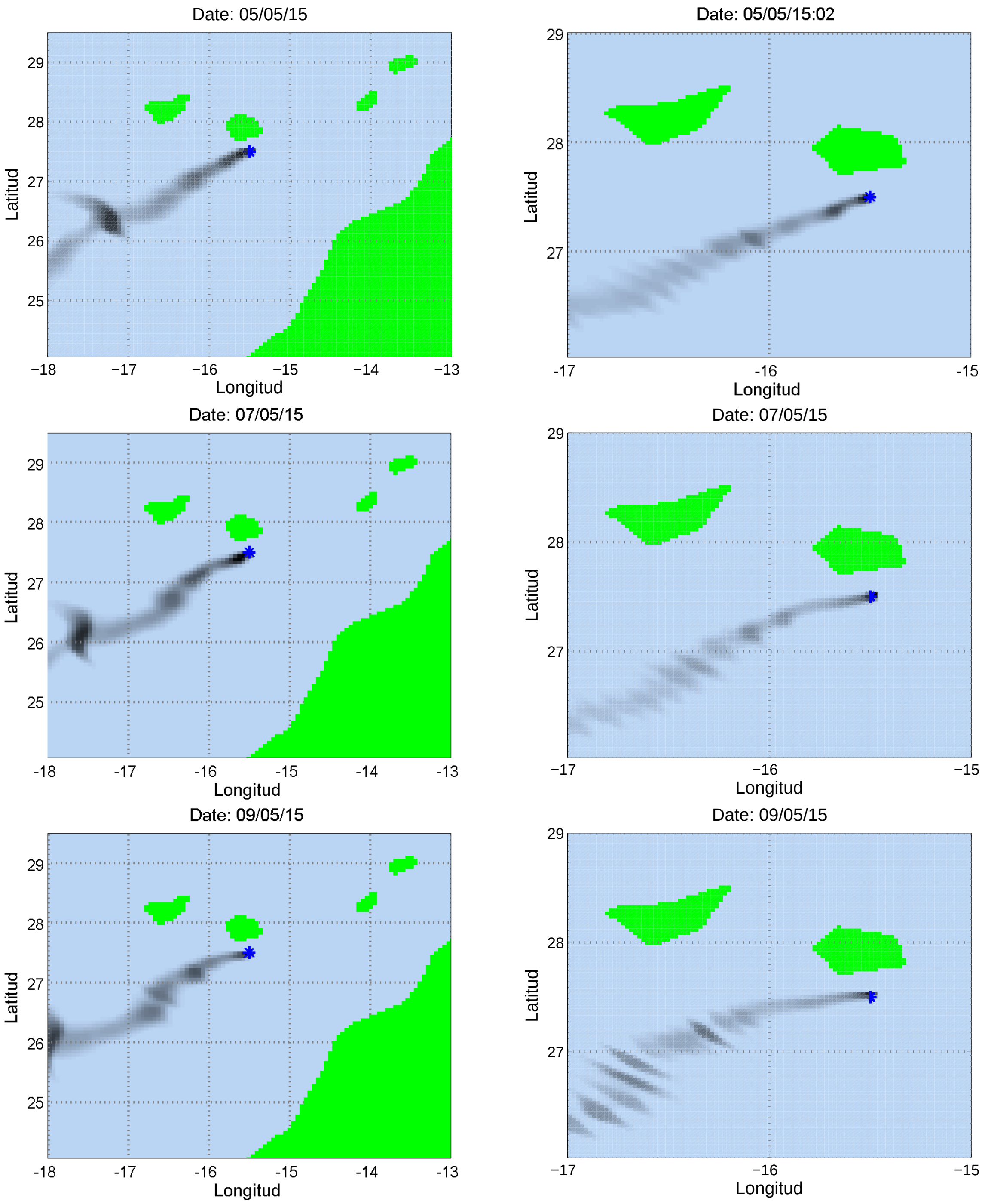

Figure 6: Oil concentration simulated by the model, considering the computational domains **(Left)** Ω and **(Right)** Ω_z,presented in this work for the dates: **(Top)** May 5, 2015, **(Middle)** May 7, 2015 and **(Bottom)** May 9, 2015. The coast is also represented in green. The position of the Oleg Naydenov ship is represented by a blue star. The drag factor is 0.022.

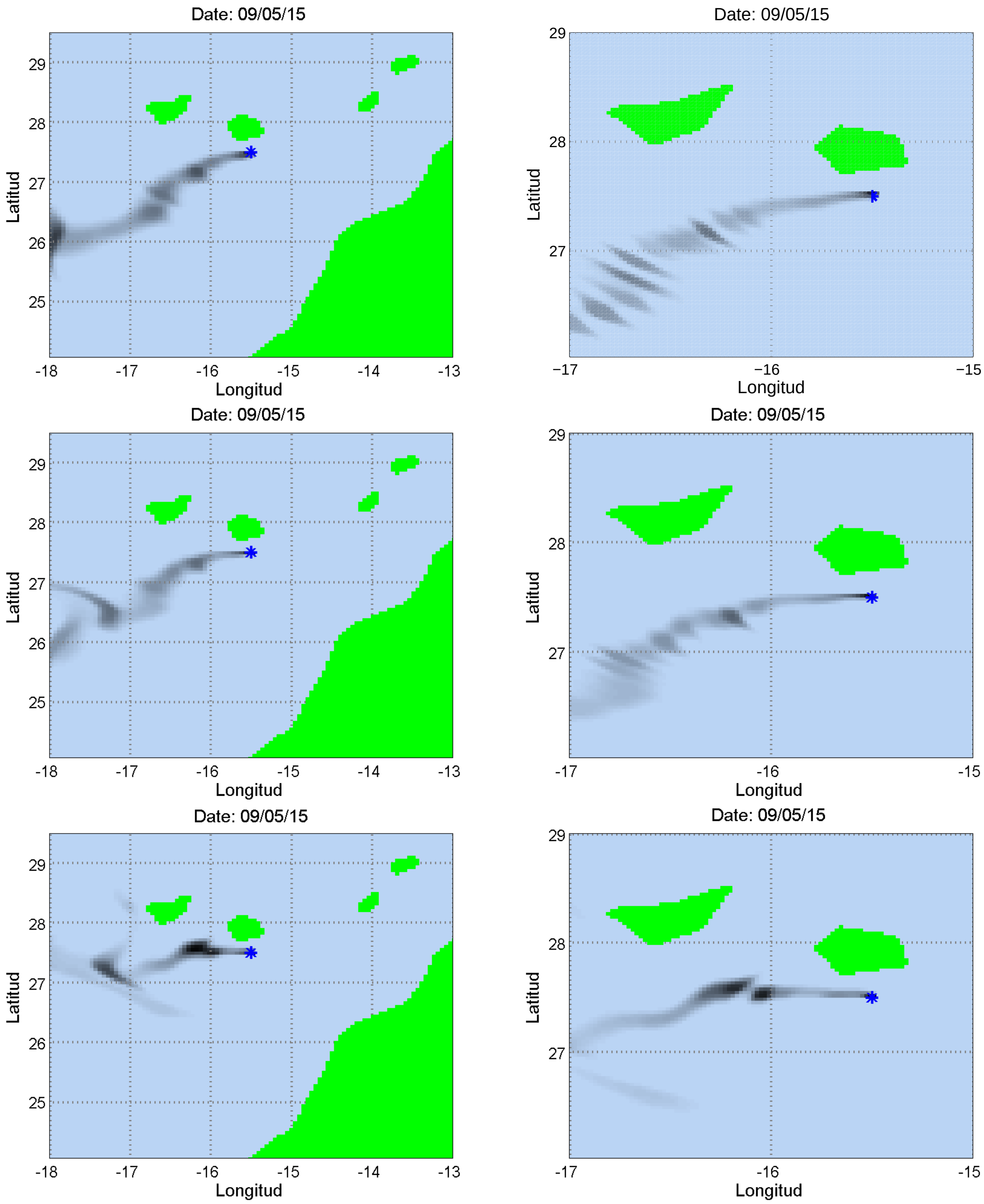

Figure 7: Oil concentration simulated by the model, considering the computational domains **(Left)** Ω and **(Right)** Ω_z,presented in this work at May 9, 2015 considering a drag factor of **(Top)** 0.022, **(Middle)** 0.011 and **(Bottom)** 0. The coast is also represented in green. The position of the Oleg Naydenov ship is represented by a blue star.

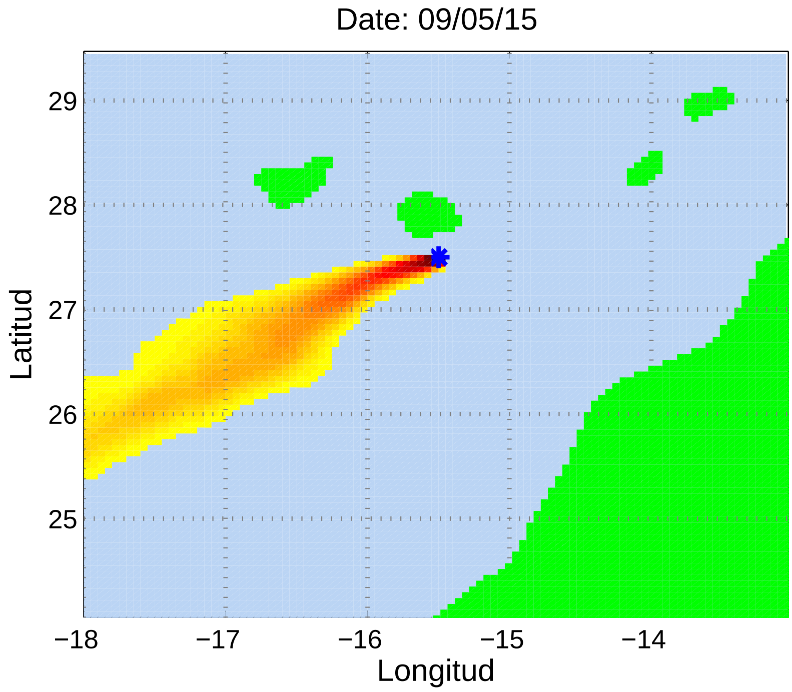

Figure 8: Most contaminated areas (from yellow to black) from April 14, 2015 up to May 9, 2015 considering the computational domain Ω. The coast is also represented in green. The position of the Oleg Naydenov ship is represented by a blue star.

4 Conclusions

In this article we have used the mathematical model discussed in [2, 5, 6], for simulating the movement of the Oleg Naydenov oil spill, taking into account wind, sea currents, diffusion and the contamination source. With this model, we were able to reproduce well the movement of the Oleg Naydenov spill at April 21, 2015. Finally, we have proposed a forecast for this particular event up to May 1, 2015 and May 9, 2015. Part of the first forecast was confirmed by real observations. Next, we have studied various forecasts up to May 9, 2015 by considering different drag factors. The main direction of the oil spill movement was south-west.

Future work will focus on the update of this forecast with recent data and the incorporation of cleaning methods in the model in order to improve their efficiency (as done in [2, 5, 6]).

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